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Integrated Agricultural Management through Environmentally Friendly Waste Processing

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Abstract: This study aims to analyze the adoption of Integrated Farming Systems (IFS) using the Technology–Organization–Environment (TOE) framework. IFS integrates agricultural, livestock, and aquaculture practices to support sustainability and improve household livelihoods. Using a quantitative approach, data were collected from farming households in Sumberagung Village, Sleman, Yogyakarta, and analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). The results show that the TOE model effectively explains 91.7% of the variance in IFS adoption. All three components—technology, organization, and environment—significantly influence the implementation of IFS, with technology having the strongest effect. These findings suggest that advancing agricultural technology, strengthening organizational capacity, and improving environmental support are essential for promoting sustainable farming practices.

Keywords: Integrated Farming System, Technology–Organization–Environment (TOE), sustainable agriculture, adoption model, PLS-SEM, rural development

1. Introduction

Waste is still the main problem facing Indonesia. Referring to data from the National Waste Management Information System of the Ministry of Environment and Forestry (KLHK), the number of waste piles reaches 19.5 million tons per year, with the most waste in the form of organic waste reaching around 12.7 million tons per year of which around 23.45% of the waste is unmanaged. This unmanaged waste will usually be buried with soil or flow through rivers to the sea. Unmanaged waste will have various adverse impacts such as reducing the value of cleanliness and beauty, causing flooding, and reducing environmental quality (air pollution, soil and water source pollution). If accumulated, the aforementioned impacts will cause various health disorders such as cancer, liver function disorders, kidney disorders and neurological disorders.

The results of an exporatory study conducted by previous researchers with the leadership of the Environmental Agency concluded that the Tamanmartani landfill owned by the Sleman local government as a waste disposal site is currently insufficient. The existence of a waste sorting machine that has been used is not effective in solving the waste problem, because the waste pulp produced has not been absorbed into the community again. This machine was made because of the large pile of waste in Indonesia due to waste that has not been sorted properly based on its type, including problems related to the accumulation of waste in landfills whose area is currently increasingly limited. The waste sorting machine is able to sort 10 tons of waste and produce at least 2.5 tons of organic waste pulp per day.

Currently, the problem of the Taman Martani Sleman Landfill is related to the difficulty of utilizing all the waste pulp produced optimally. Most of the waste porridge is only used for maggot feed because the process is easy and cheap and there is a lot of duck feed and there is still a lot left. Actually, the results of the waste processing process in the form of organic waste pulp can produce economic added value where the maggot can be used as animal feed that is able to increase egg production productivity and improve fiber quality, if used as organic fertilizer will produce high-quality fertilizer (Sugandini et al, 2023). However, to utilize 2.5 tons of waste pulp, at least 500 kg of maggot is needed. Of course, this will require additional investment, especially related to land, considering that 20 kg of maggot requires at least 66m2 of land. The special purpose of this research is to develop the results of research that has been carried out by researchers on the use of waste pulp into SNI standard organic fertilizer in the actual environment, so that the research results can be beneficial to the community and improve community welfare. The results of research related to waste slurry resulting from the sorting of waste into organic fertilizers that have been carried out previously show good data. All the composition of the mixture of waste pulp with livestock manure, Trichoderma and magot shown in table 1 shows values that are in accordance with SNI standards.

Table 1: Results of testing organic fertilizers made from waste pulp and enrichment with magot, Trichoderma and livestock manure.

No	Parameter	Satuan	Standar SNI	A	B	C	D
1	C- Organik	%	min 15	32,45	39,87	30,41	32,73
2	C/N	%	max 25	13,64	13,58	11,38	13,63
3	Kadar Air	%	10 sd 25	23,36	24,54	21,53	20,64
4	• Hara Makro • N Total • P2O5 • K2O	%	min 2	- 2,49 3,26 3,72	- 2,85 2,22 11,44	- 2,67 2,89 18,18	- 2,4 1,92 18,17
5	• Hara Mikro • Fe Total • Zn	- ppm ppm	- max 15.000 max 5.000	- 36,3 303,2	- 1001,7 404,9	- 26,3 303,2	- 1001,7 404,9
6	pH	-	4 sd 9	7,6	8,6	9,1	8,7
7	• E Coli • Salmnella	cfu/g cfu/g	<1 x 102 <1 x 102	0 0	0 0	0 0	0 0
8	• Mikroba-Fungsional • Penambata N • Pelarut P	- cfu/g cfu/g	- >1 x 105 >1 x 105	- 0 6,97 x 103	- 0 6,97 x 103	- 0 1,07 x 106	- 4,39 x 102 1,4 x 105
9	• Logam Berat • As • Hg • Pb • Cd	- ppm ppm ppm ppm	- max 10 max 1 max 50 max 2	- 0,2 0,6 41 1,8	- 0,2 0,2 17,4 1,8	- 0,2 0,2 24,2 1,3	- 0,8 0 19,2 1,5
10	Ukuran	-	Granul	-	-	-	-
11	Bahan Ikutan	%		0	0	0	0
12	Na, Cl	-	rumput laut	-	-	-	-

Source: Research results from Sugandini, Saidi, Ambarwati, Sugiharto, Kundarto (2023)

II. State of the Art

Environmental problems have threatened life in many countries. One of the factors causing global warming in addition to environmental degradation is the generation of waste (Tan et al., 2021). Effective waste management is positioned as a sustainable solution to reduce and combat the negative impacts of climate change. Countries around the world are struggling to improve household waste management (Azevedo et al., 2021). The uncontrolled pressure of large amounts of garbage accumulation causes household garbage sorting behavior to receive considerable attention (Li & Wang, 2021). Many countries still struggle with waste management systems (Campitelli & Schebek, 2020). Waste has become one of the most severe problems in urban Indonesia (Sekarningrum et al., 2020). Waste is a crucial problem in an environment where poor management can have an impact on socio-economic, health, and environmental problems. (Cao et al., 2021). The pile of accumulated waste encourages all parties to develop waste management that encourages people's behavior to sort and produce waste into organic fertilizer and recycle. Axsen et al. (2012) define pro-environmental technology as any technology that consumers perceive to have pro-environmental attributes. Pro-environmental behaviors are beneficial to the environment, such as recycling and minimizing waste production. In two studies, Kim et al. (2020) found that consumers prefer to use technology in household waste reduction campaigns. Therefore, consumers are willing to use and adopt technological devices in the context of pro-environmental actions. Manika et al. (2021) emphasize the importance of analyzing actual technology adoption behavior in future research.

1. Adoption Readiness

This study seeks to analyze the adoption of household waste management. Previous research has shown a high relationship between behavioral intentions and pro-environmental behavior (Ates, 2020; Nguyen et al., 2019). The regular use of a waste management system (WMS) to sort waste must be part of a sustainable lifestyle to condition the appropriate use of waste for the environment. Axsen et al. (2012) define pro-environmental technologies (PETs) as "any technology that consumers perceive to have pro-environmental attributes. WMS itself is one example of PET that can be used to encourage beneficial behaviors for the environment such as recycling and minimizing waste production. Pro-environmental intentions do not always succeed in producing eco-friendly behaviors (Nguyen et al., 2019); Wang et al. (2020). The UTAUT2 model from Venkatesh et al. (2012) is a theory that is considered comprehensive to analyze the adoption of technology. In this theory, behavioral intent can predict actual behavior. Venkatesh et al. (2016) and Berger & Wyss (2021) explain that the application of the UTAUT2 model requires a change in the understanding of technology in certain contexts. This study intends to adopt WMS, and the adoption behavior is the use of WMS in daily life.

2. Technology - Organization - Environment (TOE) Framework

The conceptual framework proposed in this study is the Technology-Organisation-Environment (TOE) model introduced by Tornatzky and Fleischer (1990). According to the TOE approach, a company's decision to introduce new technology is influenced by technological, organizational, and environmental factors. Some literature has explored the adoption of innovative technologies by combining the TOE framework with innovation diffusion theory so as to explain the theory of innovation diffusion from an organizational perspective that focuses more on the impact of internal and external factors (Chiu et al., 2017). The TOE framework was also used by El-Haddadeh (2019) to analyze the adoption of innovation dynamics in cloud computing in SMEs by observing the perception factors of senior managers, information technology capabilities, risk perceptions, and barriers to adoption. TOE is used as a basis to ensure the process of confirming innovations through the identification of organizations in adopting technological innovations (Kim, 2015). The TOE framework is useful in investigating various innovation contexts, such as e-commerce, e-business, and entrepreneurial resource planning to estimate the information technology readiness of SMEs (Awa et al., 2017). The TOE framework has also been used in general as a theory to test the adoption of technology in SMEs (Sabi et al., 2017; El- Haddadeh, 2019). TOE has also proven to be the framework of choice for understanding technology adoption (Sugandini et al., 2018, 2019), and the value creation that comes with new technologies (Makame et al., 2014).

3. Technological Context

The technology context focuses on internal and external technologies that are beneficial to organizations that discuss the technical knowledge needed to apply social media (Matikiti et al., 2018). The technology context represents the set of technologies available for companies to adopt. The decision to adopt a technology depends not only on what is available in the market but also on how compatible it is with the technology that a company already has (Tornatzky and Fleischer, 1990; Jeyaraj et al., 2006). Technological factors are widely studied by researchers using the diffusion theory of Rogers (2003). Innovation diffusion theory and TOE have also been commonly used in recent years in the field of information technology, such as the adoption of websites, mobile technology, and the adoption of the internet in small and medium-sized trades. There is a lot of literature that explores the use of innovative technologies by combining the TOE framework with the theory of innovation diffusion. TOE can explain the theory of innovation diffusion (Rogers 2003) from an organizational perspective and focus on the influence of innovation diffusion due to internal and external factors (Chiu et al., 2017).

4. Organizational Context

He, Wang & Zha (2014) stated that research on social media in small businesses is fundamental and needs to be studied further (Kim et al., 2013). The emergence of social media makes it easier for small businesses to acquire resources that are dominated by large companies (Kim et al., 2013). SMEs have the opportunity to compete outside of the market they currently have (He et al., 2014). Information technology helps SMEs to cut costs by improving their internal processes, faster communication with customers, and distributing their products better online. The main benefits of adopting I.T. include reducing costs, increasing productivity, improving system integration, providing a collaborative environment, and improving overall competitiveness. The findings of the MacGregor & Vrazalic (2005) study show that the lack of technical skills and knowledge about I.T. as well as the high cost of implementing I.T. are significant barriers to e-commerce adoption (El-Gohary, 2012). Ifinedo (2011) found that what causes SMEs to be reluctant to embrace internet and e-business technologies due to management's commitment/support and external pressures is a significant predictor of I.T. acceptance.

5. Environmental Context

The business environment is a major force that can encourage or hinder organizations from adopting innovation (Rogers, 2003). The external environment is the arena in which the organization conducts its business. Two central environmental pressures in the implementation of household waste management are the pressure due to the lack of acidity of the landfill, and the pressure from the accumulation of waste that needs to be addressed immediately. Another important factor is the level of national infrastructure and government involvement in encouraging the adoption of household waste management (Azevedo et al., 2021). On the other hand, the lack of regulatory support has a significant effect on the adoption of Sutter's (2012) technology.

The adoption of Integrated Farming Systems (IFS), which combines agriculture, livestock, and aquaculture in a synergistic manner, is influenced by various internal and external factors. The Technology–Organization–Environment (TOE) framework provides a comprehensive lens to examine these determinants. Technological factors such as system compatibility and ease of use can enhance adoption by reducing operational complexity. Organizational factors, including leadership, resource availability, and knowledge capacity, are critical in enabling decision-making and implementation. Meanwhile, environmental aspects such as government support, market access, and regulatory pressures can either facilitate or hinder the adoption of IFS. Based on the TOE model, the following hypotheses are proposed:

H1: Technological factors have a significant positive effect on the adoption of Integrated Farming Systems.
H2: Organizational factors have a significant positive effect on the adoption of Integrated Farming Systems.
H3: Environmental factors have a significant positive effect on the adoption of Integrated Farming Systems.

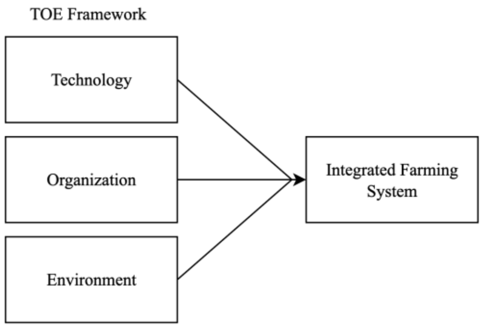

Figure 1: Conceptual Framework in Research on Integrated Agricultural Management

III. Research Method

This study explores the implementation of an Integrated Farming System (IFS) to achieve two main goals: zero emissions in agriculture and sustainable household livelihoods. Using a quantitave approach, the study focuses on households in Sumberagung Village, Moyudan, Sleman, an area suitable for IFS implementation. Loehlin (1998) states that the minimum sample size required to reduce bias in all types of SEM estimation is 200. Data were collected through direct interviews, and analysis was conducted using Structural Equation Modeling with SmartPLS. Model testing included hypothesis testing, causal relationship analysis, and goodness-of-fit evaluation. The results are interpreted based on significance levels to assess the effectiveness of IFS in improving environmental outcomes and household livelihoods.

IV. Discussion

The outer model evaluation aims to assess the validity and reliability of each construct. The analysis includes loading factor values, Cronbach's Alpha, Composite Reliability, and Average Variance Extracted (AVE). The results show that all indicators across the constructs have loading factor values above 0.70, indicating a strong contribution of each indicator to its respective construct. For instance, indicators E1–E3 for Environment range from 0.926 to 0.941; indicators IFS1–IFS4 for Integrated Farming System range from 0.923 to 0.931; indicators O1–O3 for Organization range from 0.931 to 0.942; and indicators T1–T3 for Technology range from 0.930 to 0.939. These results confirm a strong convergent validity for each construct. Furthermore, the values of Cronbach's Alpha and Composite Reliability (CR) for all four constructs exceed the recommended threshold of 0.70. Specifically, Environment scored 0.927 (Alpha) and 0.954 (CR), Organization scored 0.929 and 0.955, Technology scored 0.925 and 0.953, and Integrated Farming System scored 0.944 and 0.960. These values indicate a high level of internal consistency reliability.

Additionally, the AVE values for all constructs are well above the minimum threshold of 0.50, with the highest being 0.875 for Organization and the lowest still strong at 0.857 for IFS. These AVE values confirm a strong level of convergent validity. In terms of explanatory power, the R Square value for the Integrated Farming System (Y) is 0.917, with an adjusted R^2 of 0.916. This indicates that the combination of Technology, Organization, and Environment constructs explains 91.7% of the variance in the adoption of the integrated farming system. This is considered a very high value, demonstrating that the model has a strong predictive capability in this research context. Overall, the outer model testing results confirm that all constructs in the TOE framework are valid and reliable, and significantly contribute to explaining the implementation of the Integrated Farming System. Therefore, the model is suitable to proceed to the inner model evaluation, which tests the relationships between latent variables.

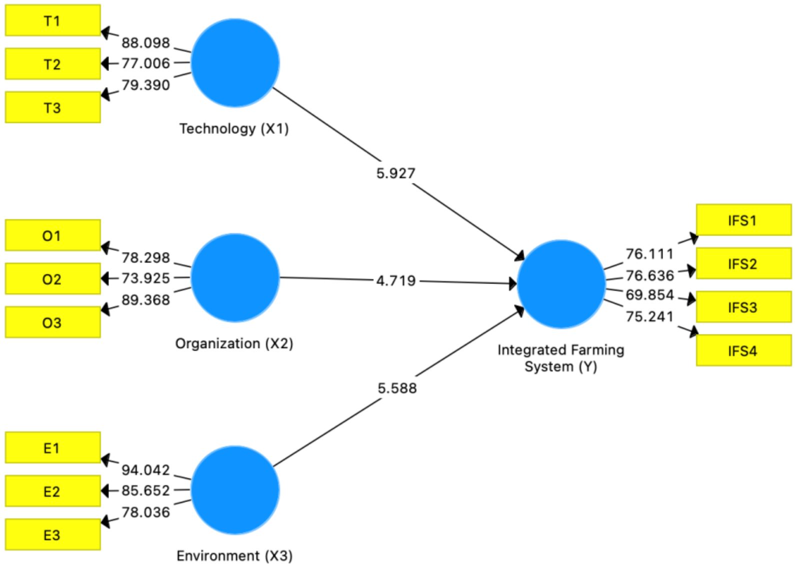

Fig. 1. Hypothesis Testing

The hypothesis testing in this study evaluates the influence of the Technology (X1), Organization (X2), and Environment (X3) variables on the Integrated Farming System (Y). The evaluation is based on the original sample coefficient (path coefficient), t-statistics, and p-values, with a significance threshold of $p \leq 0.05$.

The results show that Technology (X1) has a positive and significant effect on the implementation of Integrated Farming System, with a path coefficient of 0.346, a t-statistic of 5.927, and a p-value of 0.000. This indicates that technology is the strongest predictor among the three variables, meaning that the ease of use, accessibility, and perceived benefits of technology play a crucial role in encouraging farmers to adopt integrated farming practices.

Organization (X2) has a significant and positive impact, with a path coefficient of 0.294, a t-statistic of 4.719, and a p-value of 0.000. Although slightly lower than the others, this result confirms that internal organizational readiness, including skills, labor availability, and support from family or farmer groups, contributes meaningfully to the successful implementation of integrated farming systems.

The Environment (X3) variable also has a significant positive effect on the Integrated Farming System, with a path coefficient of 0.340, a t-statistic of 5.588, and a p-value of 0.000. This suggests that external environmental support—such as government policy, market access, and community support—significantly influences the adoption of integrated farming. Overall, all three hypotheses are supported, and the findings highlight that technology, organization, and environment are all critical and statistically significant factors in determining the adoption and success of integrated farming systems.

Based on the conceptual framework proposed in this study, the Technology–Organization–Environment (TOE) model introduced by Tornatzky and Fleischer (1990) serves as a theoretical foundation to explain the adoption of integrated farming systems. According to the TOE approach, the decision to adopt a new technology is influenced by technological, organizational, and environmental factors. This study's findings confirm that all three components significantly affect the adoption of integrated farming systems, with technology having the strongest effect, followed by environment, and then organization. These results are aligned with previous studies that have integrated the TOE framework with the diffusion of innovation theory to explore both internal and external influences on innovation adoption (Chiu et al., 2017; Kim, 2015; El-Haddadeh, 2019).

In the technology context, factors such as ease of use, perceived usefulness, and compatibility with existing farming practices play a critical role in driving the adoption of integrated farming. This supports Tornatzky and Fleischer's (1990) view that available technology and its perceived benefits shape adoption decisions. The organizational context, which includes internal readiness, skills, and support within farming groups or households, also positively influences adoption, although to a slightly lesser extent. This is consistent with Ifinedo (2011), who emphasized the importance of managerial commitment in adopting innovations.

Lastly, the environmental context, including government support, market accessibility, and social pressure, significantly contributes to adoption. This reflects Rogers' (2003) perspective on external forces and is further supported by studies such as Azevedo et al. (2021), which highlighted regulatory and infrastructural roles in innovation diffusion. In sum, the TOE framework proves to be a robust model for understanding the multifaceted influences behind the successful adoption of integrated farming systems in rural communities.

V. Conclusion

This study concludes that the Technology–Organization–Environment (TOE) framework is a valid and reliable model for explaining the adoption of Integrated Farming Systems (IFS). The outer model evaluation confirms that all constructs—Technology, Organization, and Environment—demonstrate strong reliability and convergent validity, as indicated by high factor loadings, composite reliability, and AVE values. The structural model shows that 91.7% of the variance in IFS adoption can be explained by the three TOE factors, indicating a very strong model fit. Among the three components, technology has the most substantial influence on IFS adoption, followed by environmental and organizational factors. This finding highlights the importance of accessible, compatible, and easy-to-use farming technologies, while also recognizing the role of supportive environments (e.g., policy, infrastructure) and internal organizational readiness (e.g., skills, leadership). The TOE framework thus offers a comprehensive understanding of innovation adoption in agriculture and can guide future interventions to promote sustainable farming practices.

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